Sea Ice Concentration, Ice Temperature, and Snow Depth Using AMSR-E Data

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***Abstract*—A summary of the theoretical basis and initial performance of the algorithms that are used to derive sea ice concentration, ice temperature, and snow depth on sea ice from newly acquired Earth Observing System-Aqua/Advanced Microwave Scanning Radiometer–EOS (AMSR-E) radiances is presented. The algorithms have been developed and tested using historical satellite passive microwave data and are expected to provide more accurate products, since they are designed to take advantage of the wider range of frequencies and higher spatial resolution of the AMSR-E microwave instrument. Validation programs involving coordinated satellite, aircraft, and surface measurements to determine the accuracies of these sea ice products and to improve further our capability to monitor global sea ice are currently underway.**

***Index Terms*—Algorithms, Arctic regions, microwave radiometry, sea ice, snow, temperature.**

I. Introduction

SEA ICE covers a significant fraction of the global oceans (5% to 8%) and is one of the most important parameters in the global climate system. With its snow cover, sea ice is an effective insulator that limits the exchange of energy and momentum between the ocean and atmosphere. For example, in winter, the heat flux through a thick ice cover is two orders of magnitude smaller than through an open lead [1]. A large fraction of the world's deep and bottom water is also believed to be formed at polar latitudes [2], [3]. Coastal latent-heat polynyas have been called ice factories and those near continental shelves have been identified as principal sources of bottom water [4]–[7]. The cold, dense water formed from sea ice growth in Arctic coastal polynyas also helps maintain the Arctic Ocean halocline [7], [8] that shields the ice from the warmer underlying Atlantic water. The dense water produced from ice formation can deepen the mixed layer and induce convection as is observed in the Greenland Sea Odden [9], [10]. Furthermore, with its high albedo, which ranges from about 0.70 to 0.98 for the predominant snow-covered first-year and multiyear ice [11] compared to that of the open ocean (0.10 to 0.15), sea ice reflects most of the incident shortwave radiation. This results in a sharp gradient of ocean-to-atmosphere energy flux from ice-covered oceans to ice-free regions which may give rise to violent weather systems known as polar lows [12]. New ice types (nilas and young gray ice) can have albedos as low as 0.15, but their fractional extents are considerably less than those of first-year and multiyear ice.

The most comprehensive and consistent source of global sea ice data has been satellite passive microwave sensors [13]–[15]. The first passive microwave sensor used for studying the global distribution of sea ice was the single-channel Electrically Scanning Microwave Radiometer (ESMR) which was launched on board the NASA Nimbus 5 satellite in December 1972 [13], [14], [16]. This was followed by the Scanning Multichannel Microwave Radiometer (SMMR), which was launched on board the SeaSat and Nimbus-7 research satellites in July 1978 and October 1978, respectively [13], [17]. In July 1987, the first of the series of operational passive microwave multichannel radiometers was launched as part of the Defense Meteorological Satellite Program (DMSP). This sensor, called the Special Sensor Microwave/Imager (SSM/I), operates at frequencies of 19.4, 22.2, 37, and 85.5 GHz, and measures both horizontally and vertically polarized components except at 22.2 GHz for which only a vertically polarized component is obtained. Since 1978, the multichannel sensors became the primary source of consistently derived sea ice data [18]–[22].

The launch of the Advanced Microwave Scanning Radiometer–EOS (AMSR-E) sensor on board EOS-Aqua on May 4, 2002 provides a significant improvement in our capability for monitoring the sea ice cover. Since there will be two AMSR sensors, the EOS-Aqua version is called AMSR-E while the ADEOS-II (Advanced Earth Observing Satellite) version scheduled for launch in December 2002 is simply called AMSR. Both sensors, provided by the National Space Development Agency (NASDA) of Japan, measure vertically and horizontally polarized radiances at 6.925, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz and basically have the capability of a combined SMMR and SSM/I system but with two to three times better spatial resolution. AMSR has two additional channels at 50.3 and 52.8 GHz, which are primarily used for atmospheric sounding. This means improvements in the ability to remove ambiguities in the estimates of sea ice parameters. The availability of the 6.925- and 10.65-GHz channels also allows for the determination of ice temperature, which is a standard product and can be used to further improve the accuracy of the derived ice concentration by accounting for errors associated with the spatial variability of ice temperatures. The high-resolution 89-GHz data will be used for detecting leads and small polynyas and for discriminating among different ice and surface types that may be associated with different emissivities. AMSR-E and AMSR data are expected to provide the baseline for new polar climate datasets and the means to evaluate the quality and consistency of historical satellite data.

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High-quality and consistently derived sea ice parameters are needed to ensure that the time series of these parameters are suitable for climate trend and mass balance studies.

The standard sea ice products derived from AMSR-E are sea ice concentration, ice temperature, and snow depth. These products together with the brightness temperatures are mapped to a standard polar grid currently used for SSM/I (NSIDC, 1992). These gridded products are referred to as level 3 products. The grid resolutions for the AMSR-E brightness temperatures, sea ice concentrations, and snow depth were selected to take advantage of the full spatial resolution of the AMSR-E (Table I), while still providing continuity with similar data from SMMR and SSM/I. In addition to the daily average products, we provide separate averages of ascending and descending data to enable studies of diurnal processes. The results presented in this paper make use of AMSR-E data provided by NASDA/Earth Observation Research Center (EORC) of Japan and are not yet properly calibrated. These results are, therefore, preliminary and are only meant to show that the algorithms provide reasonable results when used with AMSR-E data.

II. Sea Ice Concentration

Sea ice concentration is the principal sea ice parameter that will be derived from AMSR-E brightness temperatures. It is this product that enables the spatial characterization of the sea ice cover and the calculation of sea ice extent and area that are used in long-term trend analyses and processes studies [23]–[27]. It is also the parameter that is used to identify the location of ice edges, to quantify the area of open water within leads and polynyas, which in turn is used in salt flux and bottom-water formation studies [4]–[7].

Ice concentration products will be generated using three algorithms: the enhanced NASA Team (NT2) algorithm [20], the Bootstrap Basic Algorithm (BBA), and the AMSR Bootstrap Algorithm (ABA) [22]. The original NASA Team and BBA algorithms are currently used by the National Snow and Ice Data Center (NSIDC) for generating a climatology of sea ice from 1978 to the present using SMMR and SSM/I data. In the Arctic, the NT2 algorithm will provide the standard sea ice concentrations at both the 12.5- and 25-km resolutions using AMSR data. In the Antarctic, the BBA and the ABA algorithms will provide the corresponding concentrations at the 12.5- and 25-km resolutions, respectively. The ABA algorithm requires the 6-GHz data to account for ice temperature effects and to generate ice temperature maps. Since the resolution of the 6 GHz is too coarse for a 12.5-km resolution retrieval, we use the BBA algorithm, which makes use of the same sets of channels used in the Arctic version to generate the 12.5-km product. Results from ABA and BBA are shown to be very similar. Differences between the algorithm ice concentration retrievals at their respective resolutions will also be provided for each hemisphere.

The purpose of this paper is primarily to describe the theoretical basis for the two newest algorithms (NT2 and ABA) for generating sea ice parameters from EOS-Aqua/AMSR-E brightness temperature data. Detailed comparative analysis with other data sources have been done previously [20], [21] using SSM/I data. A similar study using AMSR-E data is not within the scope of this study. Because the NT2 and ABA algorithms are relatively new, comprehensive sea ice validation programs are currently underway and will provide the means to assess the performance of each using actual AMSR data.

TABLE I
AMSR-E Level 3 T_B and Sea Ice Datasets

PARAMETER	APPROX. RESOL.	GRID RESOL. SIZE	PRODUCT FREQUENCY
TB (6.9 GHz)	58 km	25.0 km	Daily Asc., Desc., & Ave.
TB (10.7 GHz)	37 km	25.0 km	Daily Asc., Desc., & Ave.
TB (18.7 GHz)	21 km	25.0, 12.5 km	Daily Asc., Desc., & Ave.
TB (23.8 GHz)	21 km	25.0, 12.5 km	Daily Asc., Desc., & Ave.
TB (36.5 GHz)	11 km	25.0, 12.5 km	Daily Asc., Desc., & Ave.
TB (89.0 GHz)	5 km	25.0, 12.5, 6.25 km	Daily Asc., Desc., & Ave.
Sea Ice Conc. (%)		25.0, 12.5 km	Daily Asc., Desc., & Ave.
Sea Ice Temp. (K)		25.0 km	Daily Asc., Desc., & Ave.
Snow Depth (cm)		12.5 km	5-day average

It should be noted that the microwave signatures of sea ice in the Arctic and the Antarctic are significantly different. A large fraction of the Arctic sea ice cover consists of multiyear ice floes the emissivity of which is very different from that of seasonal ice [15], while the Antarctic sea ice cover consists primarily of seasonal ice. Both algorithms may be used in either hemisphere but with the utilization of different sensor channels or algorithm coefficients.

V. Summary and Conclusion

New state-of-the-art sea ice algorithms will be used to derive sea ice concentration, ice temperature, and snow depth from AMSR-E data. Some AMSR-E data with very preliminary calibration are used to generate most of the images presented in this paper. However, the algorithms were developed using historical multichannel passive microwave datasets and still have to be validated using AMSR-E data. The accuracy of the data products is expected to be significantly improved with the AMSR-E data because of its wider range of frequencies and higher spatial resolution.

Arctic and Antarctic field programs involving coordinated satellite, aircraft, and surface measurements are currently underway to determine the accuracies of the AMSR-E sea ice products. There is also a modeling component that will provide insight into the sensitivity of each of the algorithms to variations in environmental parameters. This multinational effort is also expected to provide further improvements in our ability to monitor the earth's sea ice cover.